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Ecological effects of rehabilitation measures at the Austrian Danube: a meta-analysis of fish assemblages

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Abstract Large rivers are worldwide under severe pressure and there is a lack of information on large river restoration. The present paper represents a meta-analysis of available data on river rehabilitation projects performed at the Austrian Danube River consisting of six rehabilitation projects addressing 19 sites. The overall goal was to analyse the response of fish assemblages to different rehabilitation types based on (1) morphological type ("Instream Habitat Enhancement", "backwater Enhancement", "extended Enhancement"), (2) length of rehabilitation measure (3) time after construction (4) applied monitoring design. Biological metrics evaluated included number of fish species and relative density, habitat guilds and Leitbild species. In total, number of species increases by 55% comparing rehabilitated with unrestored sites. The number of species of all habitat guilds is higher after rehabilitation. The proportion of rheophilic species increased and the community evolved toward a more type-specific community, according to the Leitbild. Significant differences between measure types were not detected. The rehabilitation success depends mainly on its spatial extent. Highest positive response of number of rheophilic species is achieved by a length >3.9 km. The results show that habitat rehabilitation of large rivers is effective if the spatial extent of the measure is in accordance with river size.

Keywords Rehabilitation · Habitat · Large rivers · Fish · Monitoring · WFD · Austria · Danube

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Introduction

Restoration of anthropogenic modified and heavily impaired habitats has become a central effort in river ecology particularly for large floodplain rivers. An important role plays the restoration of large floodplain rivers (Schiemer, 1995; Stanford et al., 1996; Tockner & Schiemer, 1997; Schiemer et al., 1999; Tockner et al., 1999). Although, large rivers have been impacted more than any other aquatic ecosystem only a few rehabilitation projects have been completed

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worldwide and even fewer have been evaluated. Due to the large size and complexity of river/floodplain systems rehabilitation is expensive and the effects are difficult to predict.

Ecological integrity of floodplain rivers is mainly defined by the extent of the intersection between geomorphology and hydrology, resulting in a reach-specific level of habitat diversity, and habitat characteristics (Junk et al., 1989; Bayley, 1995; Ward & Stanford, 1995; Ward, 1998; Schiemer et al., 2000). Fish are good indicators of ecological integrity in floodplain rivers since the various guilds integrate a wide range of riverine conditions from bed sediment structure for egg development to longitudinal connectivity for spawning migrations (Copp, 1989; Persat et al., 1995; Schiemer et al., 1991, 2000). Studies of endangered fish species show that both, species preferring flowing water (rheophilic species) and stagnant water (limnophilic), are at risk (Lelek, 1987; Schiemer & Spindler, 1989; Schiemer & Waidbacher, 1992; Guti, 1995; Wolter et al., 1999; IUCN, 2000; Buijse et al., 2002).

The reference conditions, so-called Leitbild, are well-defined for the Austrian Danube River (ADR), and reveal many deficiencies of the current conditions compared to those prior to channelization (Hohensinner et al., 2004, 2011) when the system was anabranched and consisted of more than 90% lotic water bodies (Fig. 1). Over the long-term, erosion, and aggradation presumably remained in a dynamic equilibrium. River channelization primarily led to a stabilization of the former morphodynamic processes (Hohensinner et al., 2008). About 80% of the ADR has been dammed in the second half of the twenties century. This resulted in an alteration of the active channel conditions, interruption of the longitudinal and lateral continuity, and decoupling and loss of floodplain habitats. Fish populations declined dramatically according to the extended loss of ecological functioning of the river/floodplain system. Rehabilitation of the ADR started in the nineties and covers both impounded and free flowing river sections.

The present paper represents a meta-analysis of available data on river rehabilitation projects performed at the ADR. The aim of this paper is to provide an overview on different rehabilitation types and their efficiency evaluated by the indicator fish. The following hypotheses were: (1) Rehabilitation has a positive influence on the number of fish species and fish community structure depending on the morphological rehabilitation type, length of rehabilitation, and time lag after construction. (2) The fish community significantly evolves toward the Leitbild after rehabilitation.

Materials and methods

Source of information, extracted parameters, and classifications

In total, six monitoring projects were analysed (Rezner, 2001; Zauner et al., 2001, 2008; Ginzler, 2002; Schabus & Reckendorfer, 2006; Keckeis et al., 2007) describing 19 different sites with rehabilitation projects (Fig. 2). According to the designations of the BAW Leitbildkatalog 2011 which refer the reference conditions, site 1–4 are located in the adapted Leitbild Danube section "Oberes Donautal Passau–Aschach", site 5–7 in "Wachau Melk–Krems", and site 8–19 in "Tullner–Wiener Becken, Krems–Hainburg". Due to the channelization of the Austrian Danube in the nineteenth century the Danube has a uniform profile with a river width of 270–300 m in studies areas. Sampled habitats are located along the shoreline with a maximum water depth of 2–3 m.

Rehabilitation projects were grouped in three categories. The rehabilitation type "Instream Habitat Enhancement" (IHE) refers to structures designed to increase the variability of habitat parameters (e.g., width, depth, velocity) within the river channel (gravel banks: site 4, 7, 8, and 19, hook groynes: site 2 and 3). The rehabilitation type "backwater Enhancement" (bE) was used for habitat enhancement implemented within impoundments (small lentic backwaters: site 12 and 15, small backwaters with low flow velocity: site 9–11, 13–14, and 16). The rehabilitation type "extended Enhancement" (eE) refers to measures providing the possibility of dynamic bank development (removal of rip rap along the shoreline: site 1, 17, and 18) including erosion and deposition processes and/or created/connected side arms (site 6) or oxbow lakes (site 5) (Fig. 3).

Ecological guilds appear to be good indicators of the ecological integrity and functioning of river–floodplain systems (Aarts et al., 2004). Zauner & Eberstaller (1999) developed a classification scheme for the Austrian fish fauna that categorizes species into groups with similar ecological requirements.

Fig. 1 Original anabranched section of the Danube River in Vienna (Schweickhardt 1830–1846)

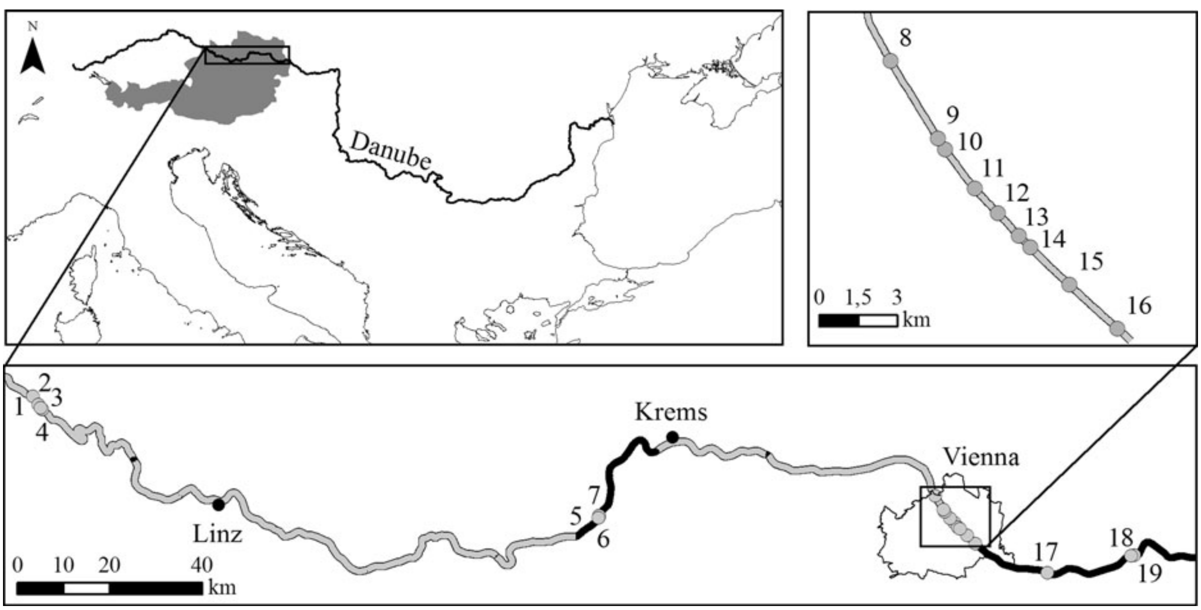
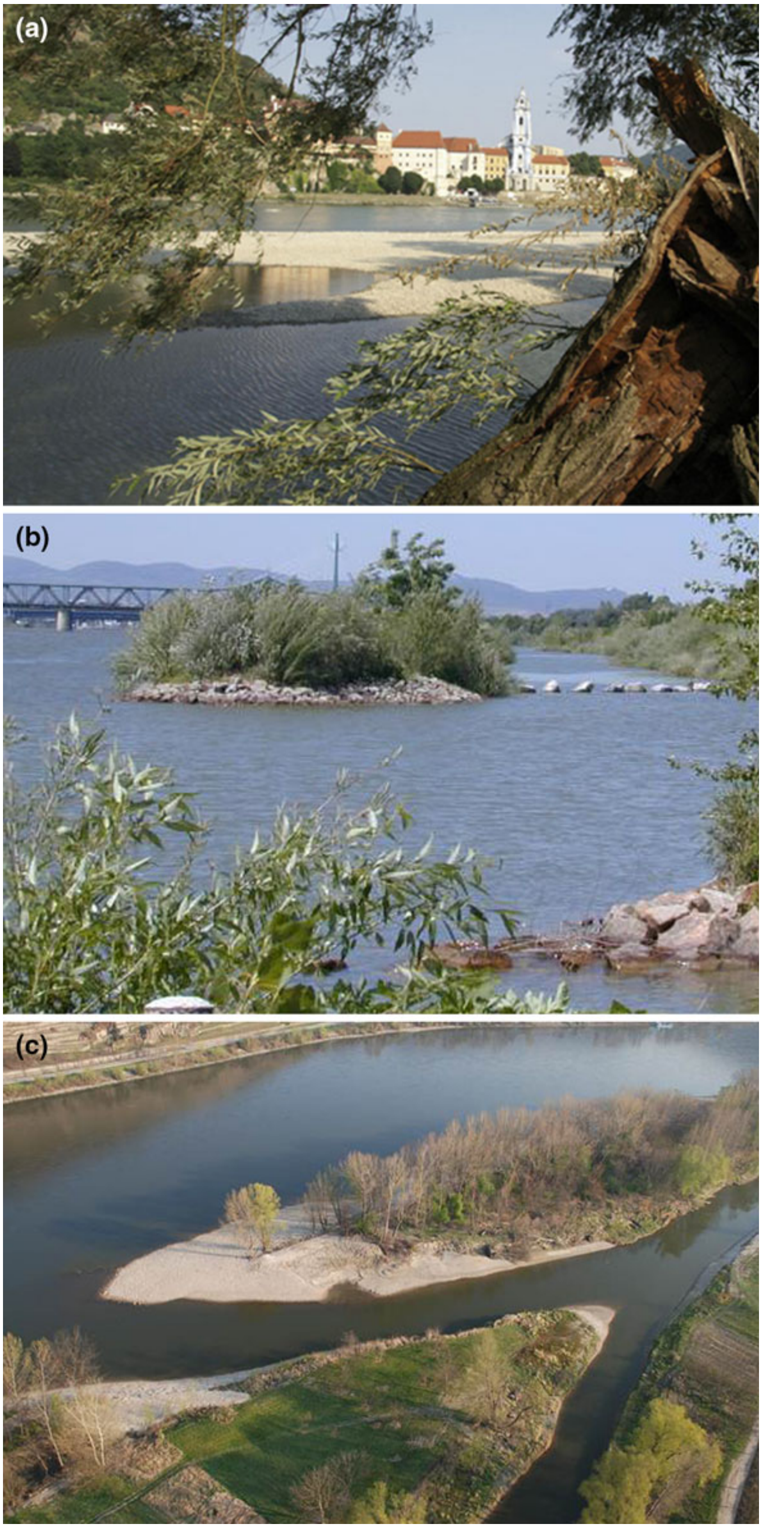


Fig. 2 Study area with site IDs. Impounded sections in *gray*, free flowing sections in *black*

Fig. 3 Categories of rehabilitation types: **a** IHE with gravel banks. **b** bE in dammed river section in Vienna. Backwater with stagnant water. **c** eE provides side erosion due to removal of rip rap and connects side arms to the main channel



Therefore, fish species were grouped into three habitat guilds, i.e., rheophilic, eurytopic, and limnophilic according to the EFI+ classification. The European Fish Index is a multimetric index based on a predictive model that derives reference conditions from abiotic environmental characteristics of individual sites and quantifies the deviation between the predicted fish community (in the "quasi absence" of any human disturbance) and the observed fish community (described during a fish sampling occasion). The metrics used are based on species guilds describing the main ecological and biological characteristics of the fish community (http://efi-plus.boku.ac.at/software/doc/Annexes.pdf). Furthermore, species were classified according to their Leitbild classification, a classification referring to the historic abundance, as defined and used in the Austrian Fish Index—FIA, the national method for the Water Framework Directive—WFD (BAW 2011): key species, accompanying species, and rare species. We used these metrics to analyse overall composition of fish assemblages independent of habitat requirements, to compare rehabilitation success with historic conditions and to assess if metrics used for the FIA are able to detect rehabilitation success.

The BACI methodology (before–after–control–impact) was applied at sites (17–19), before–after (BA) at sites (1–4) and control–impact (CI) at sites (5–16). For our analyses we compared B (1–4, 17–19) or C (5–16) data with data of rehabilitated sites (Table 1). For data consistency we only used BA data from studies with BACI methodology. Sampling efforts were approximately the same before and after rehabilitation, respectively, at control and rehabilitation sites. Fish sampling methodology was catch-per-unit-effort. Sampling was done mainly by electrofishing supplemented by riparian trawling and longline fishing but sampling techniques varied among sites. Therefore, we used only number of species and the relative densities of the different habitat guilds and Leitbild categories as fish metrics. As accurate abundance estimates of the small-sized and bottom-dwelling species bullhead (*Cottus gobio* L.) are difficult to obtain, all abundance analyses were done without this species.

We tested co-linearity of the independent variables length of rehabilitation [m], time after rehabilitation [a], type of rehabilitation (IHE, bE, eE), and type of monitoring design (CI, BA) with a pair-wise correlation matrix using Spearman rank correlation. Non parametric tests with related samples (Wilcoxon Test) were computed to compare values of number of species and relative density for habitat guilds and Leitbild classifications for all sites and each rehabilitation type. For further analyses we calculated the difference of number of species and relative densities after rehabilitation. Since conventional methods, such as linear regression analysis, are only suitable to show main effects and indirect interactions, the chosen alternative was a Decision Tree procedure (SPSS PASW® Decision Trees 18) which is a graphical non-linear discriminant analysis. The outcome allows the testing and clear wording of hypotheses. Classification and Regression Trees (CRT) splits the data into segments that are as homogeneous as possible with respect to the dependent variable. A terminal node in which all cases have the same value for the dependent variable is a homogeneous, "pure" node. The proportion of variance explained by the model is:

$$\eta^2 = 1 - \left(\frac{\text{within} - \text{node variance (risk)}}{\text{total variance}}\right)$$

The total variance is the variance for the dependent variables before consideration of any independent variables, which is the variance at the root node (SPSS PASW® Decision Trees 18, Chapter 5, p 22).

CRT models were built for two dependent variables, i.e., change in number of total species and rheophilic species. The advantage of the CRT procedure is the ability to figure out the main effects and the direct interactions. Furthermore, the procedure processes both categorical and metric data formats (De'ath & Fabricius, 2000). CRT is adequate for our data set since the procedure splits the variables subsequently in two classes instead of multiple (which is appropriate for bigger data sets).

Furthermore, non parametric tests (Kruskal–Wallis Test) were computed to compare rehabilitation types (IHE, bE, eE) concerning habitat guilds, and Leitbild classifications. Linear regression models were computed for the length of rehabilitation and time after rehabilitation concerning habitat guilds, Leitbild classification, and the parameters number of species and relative density. The level of significance was $P < 0.05$. All statistics were calculated using SPSS PASW.

Table 1 Overview of monitoring study design

Monitoring study	Monitoring design	Number of treatment sites	Number of control sites	Number of years before	Number of years after	Status
Zauner et al. (2001)	BA	4	0	4	6	Impoundment
Zauner et al. (2008)	CI	3	1	0	0.5	Free flowing
Rezner (2001) and Ginzler (2002)	CI	9	3	0	4	Impoundment
Schabus & Reckendorfer (2006)	BA(CI)	1 (4)[a]	1 (2)[a]	2	0.5	Free flowing
Keckeis et al. (2007)	BA(CI)	2	2	0.5	0.5	Free flowing

[a] Cumulative data set in the oxbow-system Orth

Results

General success of rehabilitation

Correlations among independent variables were only significant between length and time after rehabilitation ($P = 0.027$, correlation coefficient $= -0.507$). The proportion of variance explained by the decision tree model is 68% for the increase of number of species after rehabilitation. The incorporated independent variables were length of rehabilitation, rehabilitation type, and monitoring design. The first division incorporates the variable length of rehabilitation (mean increase of ten species at a scale >1,000 m and seven at a scale ≤1,000 m). Second division incorporates monitoring design at a scale >1,000 m with a mean increase of twelve species for CI and six for BA. At a scale ≤1,000 m the model incorporates the variable rehabilitation type and predicts a mean increase of six species for bE and two species for IHE and eE. The variable time after rehabilitation was not included in the model.

In total, median number of species increased about 55%, from 11 before to 17 after rehabilitation. The maximum increase was an increase of 15 species found in site 5 and 6 (both from 16 to 31) (Fig. 4). Median species values of different habitat guilds increased from five to eight for both, rheophilic (+26% relative density) and eurytopic (−38% relative density), and from zero to one for limnophilic species (Fig. 5). Proportions of relative density of rheophilic and eurytopic species are more evenly distributed after rehabilitation respectively at rehabilitated sites compared to control sites (Fig. 5). The relative densities of rheophilic and eurytopic species are highly dependent since limnophilic species have very low abundances. Median species values of Leitbild classification increased from 4 to 5 for key species (+37% relative density), from 5 to 7 for accompanying species (−23% relative density), and from one to three for rare species (+3% relative density) (Fig. 6). Median number of exotic species increased from one to two, however, relative density decreased by 17% (see Appendix in supplementary materials). The common nase (*Chondrostroma nasus* L.) reached the highest mean increase of relative density with >20% at all 19 sites.

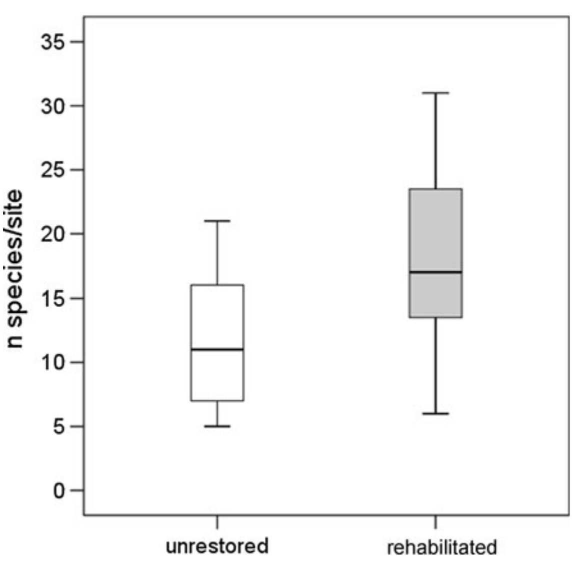


Fig. 4 Median (*black bar*), 25 and 75% percentile (*box*), and minimum/maximum (*whiskers*) of number of species/site at unrestored (*white*) and rehabilitated (*gray*) sites

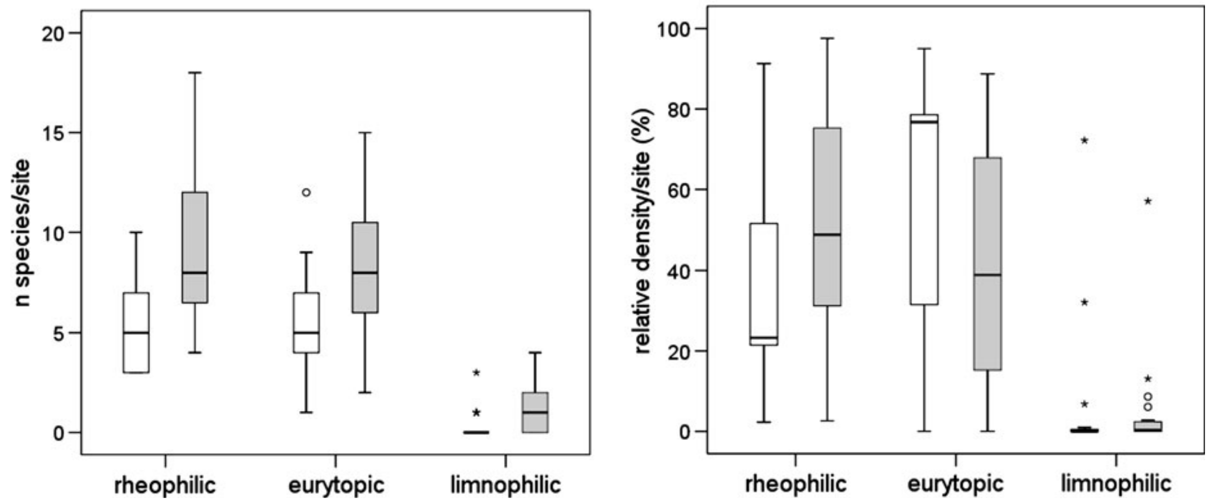


Fig. 5 Median (*black bar*), 25 and 75% percentile (*box*), and minimum/maximum (*whiskers*), outliners (*open circle*) and extreme values (*asterisk*) of number of species (*left*) and relative density/site (*right*) at unrestored (*white*) and rehabilitated sites (*gray*) for three habitat guilds (*RH* rheophilic, *EURY* eurytopic, and *LIMNO* limnophilic)

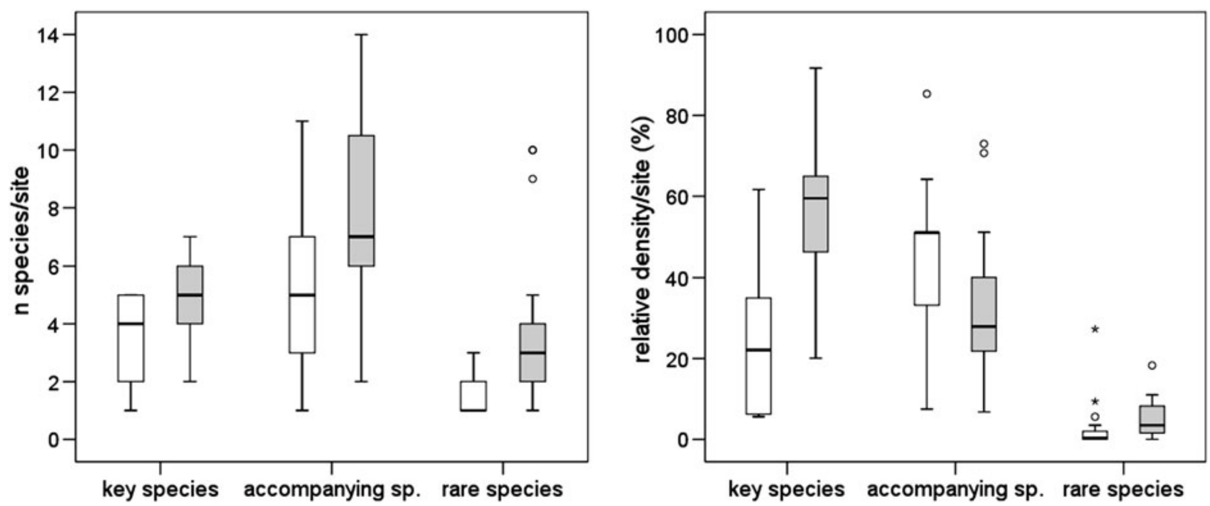


Fig. 6 Median (*black bar*), 25 and 75% percentile (*box*), and minimum/maximum (*whiskers*), outliners (*open circle*) and extreme values (*asterisk*) of number of species (*left*) and relative density/site (*right*) at unrestored (*white*) and rehabilitated sites (*gray*) for three Leitbild classifications (*KS* key species, *AS* accompanying species, *RS* rare species)

Rehabilitation types

The number of species significant increased after rehabilitation in all rehabilitation types (Wilcoxon Test, Table 2). The highest number of species occurred in type eE with 31 species after rehabilitation, followed by IHE with 29 species. The lowest number of species was observed in bE with 19 species. Significant differences between unrestored and rehabilitated values of number of species and relative density within rehabilitated types for habitat guilds and Leitbild classification are shown in Table 2 in bold print (Wilcoxon Test).

Significant differences were only detectable among rehabilitated types for number of key species (Kruskal–Wallis, $P = 0.021$) with the highest increase for bE (eight sites). The results show that within all habitat guilds and Leitbild classifications the number of species increased after rehabilitation in all types. While the relative rheophilic density increased the one

Table 2 *p* values of unrestored versus rehabilitated values for number of species/relative density, habitat guilds (rheophilic: *RH*, eurytopic: *EURY*, limnophilic: *LIMNO*), Leitbild classification (key species: *KS*, accompanying species: *AS*, rare species: *RS*), and rehabilitation type (Instream Habitat Enhancement: *IHE*, backwater Enhancement: *bE*, extended Enhancement: *eE*) (Wilcoxon test)

	n_sp	RH	EURY	LIMNO	KS	AS	RS
All sites (19)	**.000**	**.001/.003**	**.000/.005**	**.015**/.470	**.002/.000**	**.000**/.064	**.001/.005**
IHE (6)	**.003**	**.043**/.249	.058/.345	.414/.465	.257/.345	**.028**/.753	**.042**/.249
bE (8)	**.000**	–	–	–	–	–	–
eE (5)	**.005**	.068/**.043**	.066/.068	.257/.893	.063/**.043**	.141/.893	.068/.138

Number of sites in brackets. Significant differences are in bold

of eurytopic decreased (Fig. 7). No significant differences were detectable between rehabilitation types. The highest increase of relative density was reached by the common nase in IHE and eE, and bleak (*Alburnus alburnus* L.) in bE (data not shown).

Effect of length of rehabilitation measure

The length of rehabilitation was highly variable (average = 1.8 km; range = 50 m–9.7 km). The number of rheophilic species (linear regression, $P = 0.025$, $r^2 = 0.263$, $y = 0.001x + 2.539$) and the relative rheophilic density (linear regression, $P = 0.042$, $r^2 = 0.222$, $y = 0.005x + 9.037$) is significantly positively correlated with the length of rehabilitation [m]. In contrast, the relative eurytopic density significantly decreases with increasing length of rehabilitation [m] (linear regression, $P = 0.043$, $r^2 = 0.22$, $y = -0.005x - 7.625$).

Time effect

The monitoring time varied from a half to 6 years after rehabilitation (average = 3.3 years). Analyses revealed a significant influence of time on the number of rare species (linear regression, $P = 0.039$, $r^2 = 0.228$, $y = -0.596x + 4.241$), relative accompanying species density (linear regression, $P = 0.027$, $r^2 = 0.257$, $y = -4.579x + 6.894$), and relative rare species density (linear regression, $P = 0.011$, $r^2 = 0.324$, $y = 1.039x - 1.047$). While the number of rare species and relative accompanying species density decreased the relative rare species density increased with time. All other analyses showed no significant time effect.

Change in number of rheophilic species after rehabilitation

The proportion of variance explained by the decision tree model is 75% ($\eta^2 = 0.753$) for the change in number of rheophilic species. The incorporated independent variables were length of rehabilitation and rehabilitation type. The mean increase for the number of rheophilic species after rehabilitation (Fig. 8) is nine species for a length greater than 3,850 m (Node 2), and five for a length less or equal 3,850 m and greater than 1,150 m (Node 4). For a length less or equal 1,150 m the model further includes the

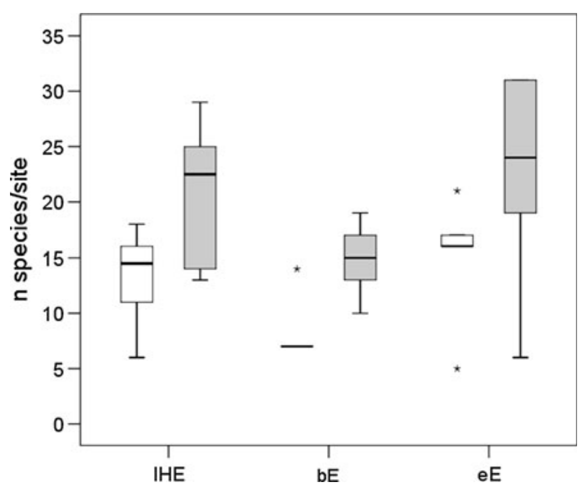


Fig. 7 Median (*black bar*), 25 and 75% percentile (*box*), and minimum/maximum (*whiskers*), and outliers (*asterisk*) of relative density following three rehabilitation types (*IHE* Instream Habitat Enhancement, *bE* backwater Enhancement, *eE* extended Enhancement) and type of habitat guild (*white RH* rheophil, *light gray EURY* eurytop

independent variable type of rehabilitation and predicts a mean increase of three species for bE (Node 5).

Discussion

In general, all rehabilitation projects realized at the ADR showed positive effects for fish diversity and abundance. The number of species increased by 55% after rehabilitation. This was a quite consistent pattern across all sites, only one single site (ID 4) showed a contrasting trend, i.e., the number of species decreased by one species. The rehabilitation type at this site was an "IHE" consisting of a 500 m uniform gravel bank.

The relative abundance of rheophilic species increased while in consequence, since limnophilic species in general show very low abundances, eurytopic species decreased after rehabilitation. Since species that are highly adapted to riverine conditions have declined far more than generalist species in degraded rivers (Aarts et al., 2004) our results demonstrate that this process can be reversed by river rehabilitation at least at the local scale.

Our results are in accordance with evaluations of river–floodplain restoration at the lower River Rhine by Grift et al. (2001), revealing consistent results along a gradient of flow and connectivity. They concluded that the creation of new floodplain waters with a permanent connection and a constant, moderate flow probably has the highest potential for supporting rheophilic fish community in the River Rhine. Furthermore, rehabilitation at the ADR increased the abundance of key and rare species.

Techniques used to IHE along the ADR, e.g., construction of hook groynes and introduction of gravel bars enhanced fish diversity and abundance and lead to an increase in Leitbild species. While Roni et al. (2008) found that firm conclusions for IHE structures were impossible because of the limited information provided by the reviewed literature Feld et al. (2011) found, in accordance with our results, that fish communities benefit from instream habitat restoration.

Sites classified as "bE" are located at the Vienna Danube Island shoreline and are characterized by urban development, channel straightening and the construction of a hydroelectric power plant. Due to the increased habitat diversity, refuges from massive wave disturbances caused by navigation, and sufficient connection to the main river channel a surprisingly high number of fish species has been attracted by the constructed habitats. Side arm structures in the more lenitic central impoundment are mainly important for eurytopic species but also host young age classes of rheophilic species, and provide sufficient prey fish for predators such as pike (*Esox Lucius* L.) and perch (*Perca fluviatilis* L.) (Chovanec et al., 2002). Nevertheless, the strong increase in key species number resulted from the low number of fish species at the control sites (average number of species at control sites: bE = 9, IHE = 13, eE = 15); a situation often

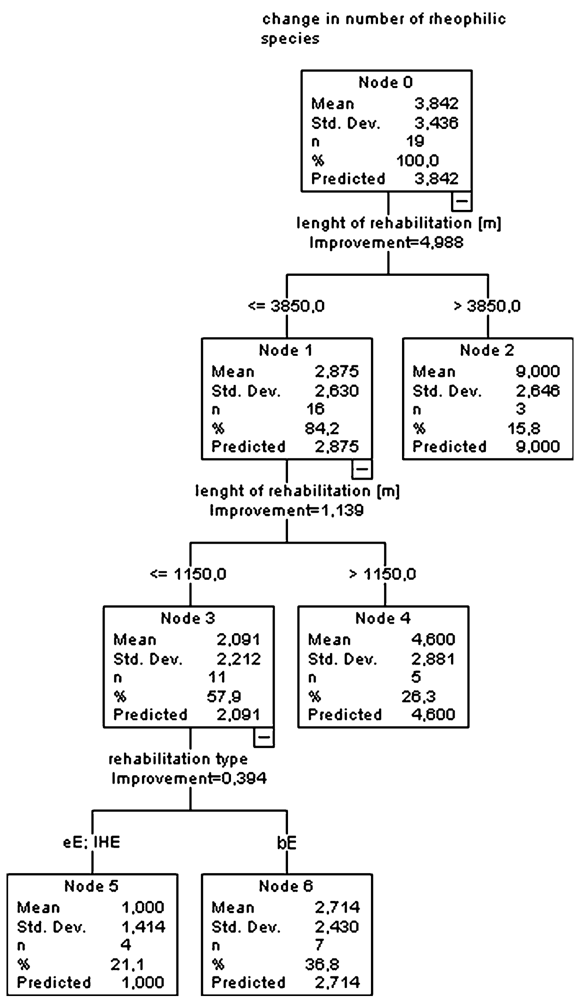


Fig. 8 Decision tree for the change in number of rheophilic species after rehabilitation and the independent variables length of rehabilitation measure [m], time after restoration [a], type of rehabilitation (*IHE* Instream Habitat Enhancement, *bE* backwater Enhancement, *eE* extended Enhancement), and monitoring design (*BA* before–after, *CI* control–impact)

found in heavily degraded, urban rivers (e.g. Wolter & Vilcinskas, 2000; Paul & Meyer, 2001; Miltner et al., 2004). Regrettably, the created habitats lose their function during floods—when the water level of the impoundment is lowered for flood protection—causing complete dewatering of the habitats.

The best improvement is achieved by "eE" with the highest number of fish species after rehabilitation and a significant increase of both rheophilic and key species density. eE includes oxbow lakes, side arms and dynamic river banks and the highest effect of a 60% increase in rheophilic abundance is achieved in side arms with permanent flow. Also rare species showed an increase but only for sites where side arms or oxbow lakes were connected (ID 5 and 6, data see Appendix in supplementary materials). Those sites further host the highest number of Leitbild species after rehabilitation. Grift et al. (2001) found in the lower River Rhine that compared to the groyne fields and floodplain lakes that were already present before floodplain restoration, secondary channels, and reconnected oxbow lakes provided habitats that were significantly better suitable for 0+ fish and formed important spawning and nursery habitats for rheophilic cyprinids.

We found that limnophilic species increased only marginally and are still rare. In the main channel, they may even indicate degradation due to river damming. They are better indicators for measures in the floodplains (Grift et al., 2006). Grift et al. (2001) found that limnophilic species originally dominating in floodplains have disappeared after reconnection. It would appear that limnophilic species would need rehabilitation of larger isolated water bodies (Schomaker & Wolter, 2011). However, the low level of limnophilic species is consistent with the Leitbild prior to channelization when the system was anabranched and consisted of more than 90% of lotic water bodies (Hohensinner et al., 2004, 2011).

The Austrian Danube has still a high potential for rehabilitation as only long-distant migratory sturgeons have become extinct in the past. Recolonisation of rehabilitated sites is therefore possible for a wide spectrum of species. Stocking of fish is uncommon in the Danube and mainly related to flag fish species such as Danube salmon (Hucho hucho). The fish populations rely on natural reproduction. Therefore, the significant increase of species in the rehabilitated sites clearly reflects the still high potential of the Danube and is unlikely influenced by stocking.

Native species are increasingly considered to be impaired or even threatened by invasive species in the Danube River Basin (Paunovic & Csányi, 2010; Bloesch et al., 2011). We documented seven exotic species (out of 38) at unrestored, and eleven exotic species (out of 49) at rehabilitated sites (Appendix S2 in supplementary materials). This is supported by Burgess et al. (2012) who postulated that maintaining floodplain–mainstem river connectivity can also facilitate invasions of non-native species to these habitats. Although the number of non-native species increased slightly, the relative abundances decreased significantly at rehabilitated sites: especially the species *Neogobius melanostomus* L. and *Neogobius kessleri* L. which occurred in high densities in the rip rap sections, but almost disappeared in the newly created habitats.

As expected, the success of rehabilitation increased with the length of rehabilitation as shown in the decision trees for the general number of species and the number of rheophilic species. This is important, since it implies that no matter which type of measure is used, the larger the area treated the result. In other words, there is no difference among the construction of gravel bars, hook groynes or other instream structures and the creation/connection of side channels or oxbows, until the measure reaches a certain size. Our results show that improvement of habitat for rheophilic species is achieved by the construction of gravel banks and hook groynes at a scale of more than 3.8 km and by bE at a scale less than 1.2 km. The latter is explained by the high habitat diversity at a comparable small scale and the low number of species at control sites. However, as mentioned above, bE do provide only temporal habitats that are eliminated during floods.

Co-linearity in the data set was tested between all independent variables and revealed significant but low correlations only between time and length after rehabilitation. The other combinations were evenly distributed. Observed co-linearity did not affect our model, as correlating variables are not included in the regression tree model.

There was no visible time effect in our dataset which is mainly due to the lack of repeated samples. To better understand the long-term effects of rehabilitation, more long-term monitoring programmes are needed.

Although the response of the fish communities was strong after rehabilitation among all rehabilitation types, we have to take into account that in areas where dynamic regeneration processes are lacking, fixed structures will lose their function by silting up and becoming de-coupled from the main river unless regular and cost expensive maintenance measures are implemented. The overall goal of rehabilitation should be to establish conditions that enable self-sustaining, e.g., dynamic processes that provide all relevant functions of the river–floodplain system in line with the Leitbild (Muhar et al., 1995, 2000; Buijse et al., 2005).

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